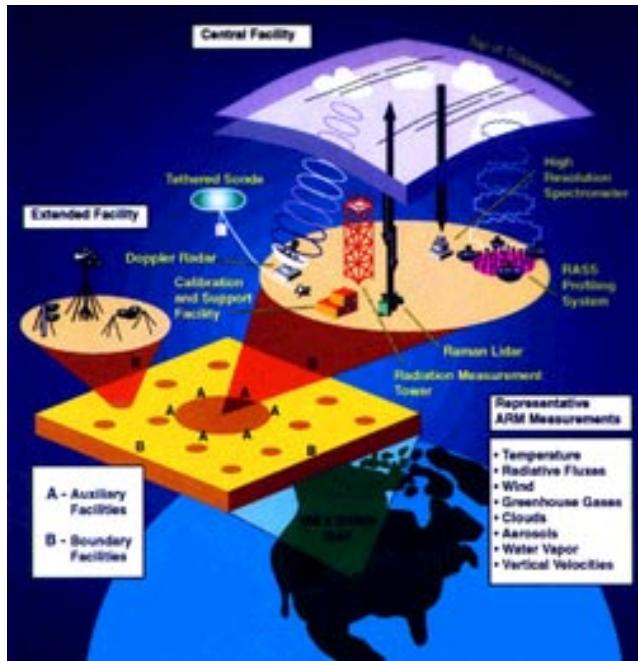


AEROSOL RADIATIVE INFLUENCES AT SGP

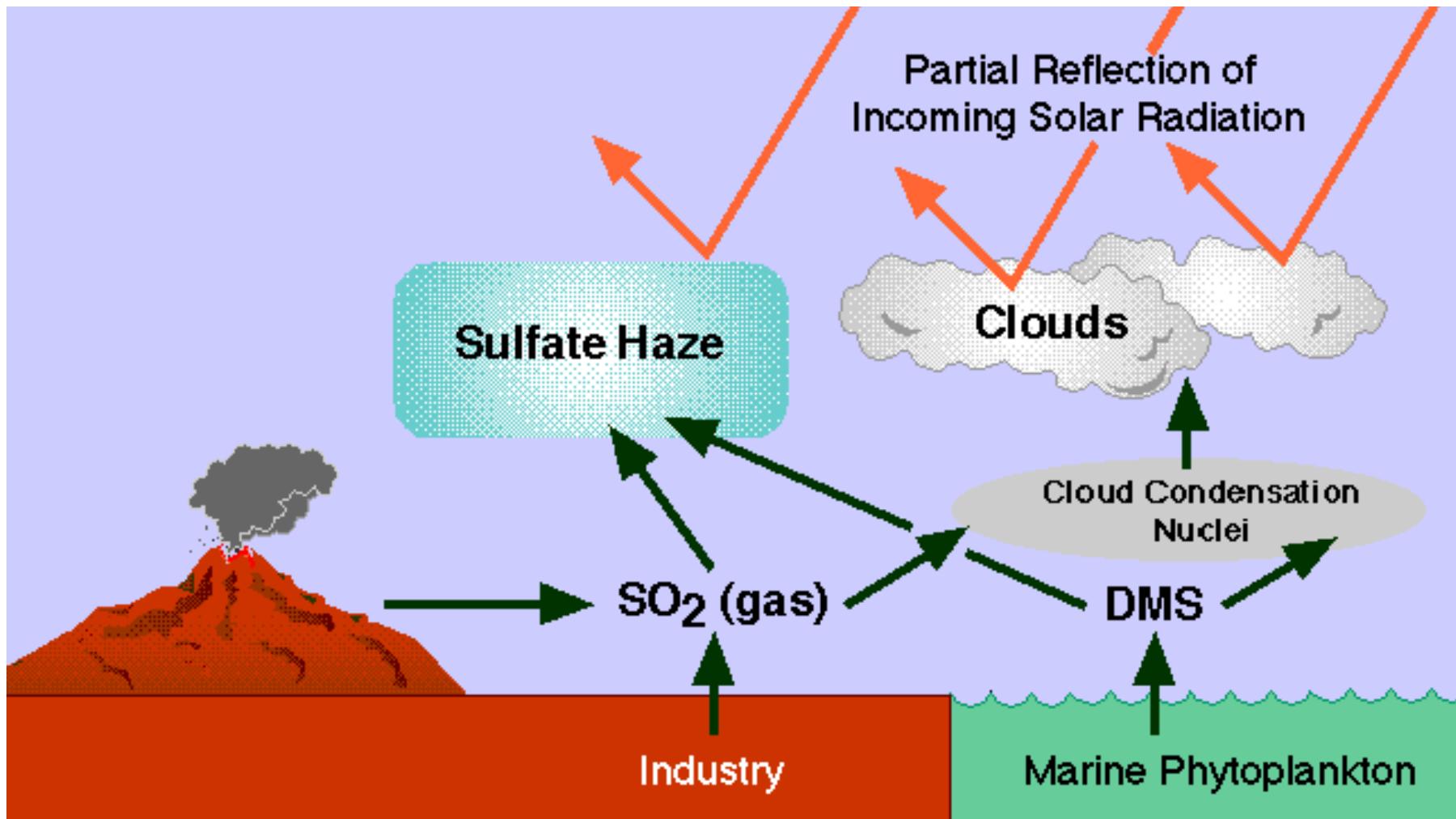
Stephen E. Schwartz



Fourteenth Science Team Meeting
Albuquerque NM
March 22-26, 2004

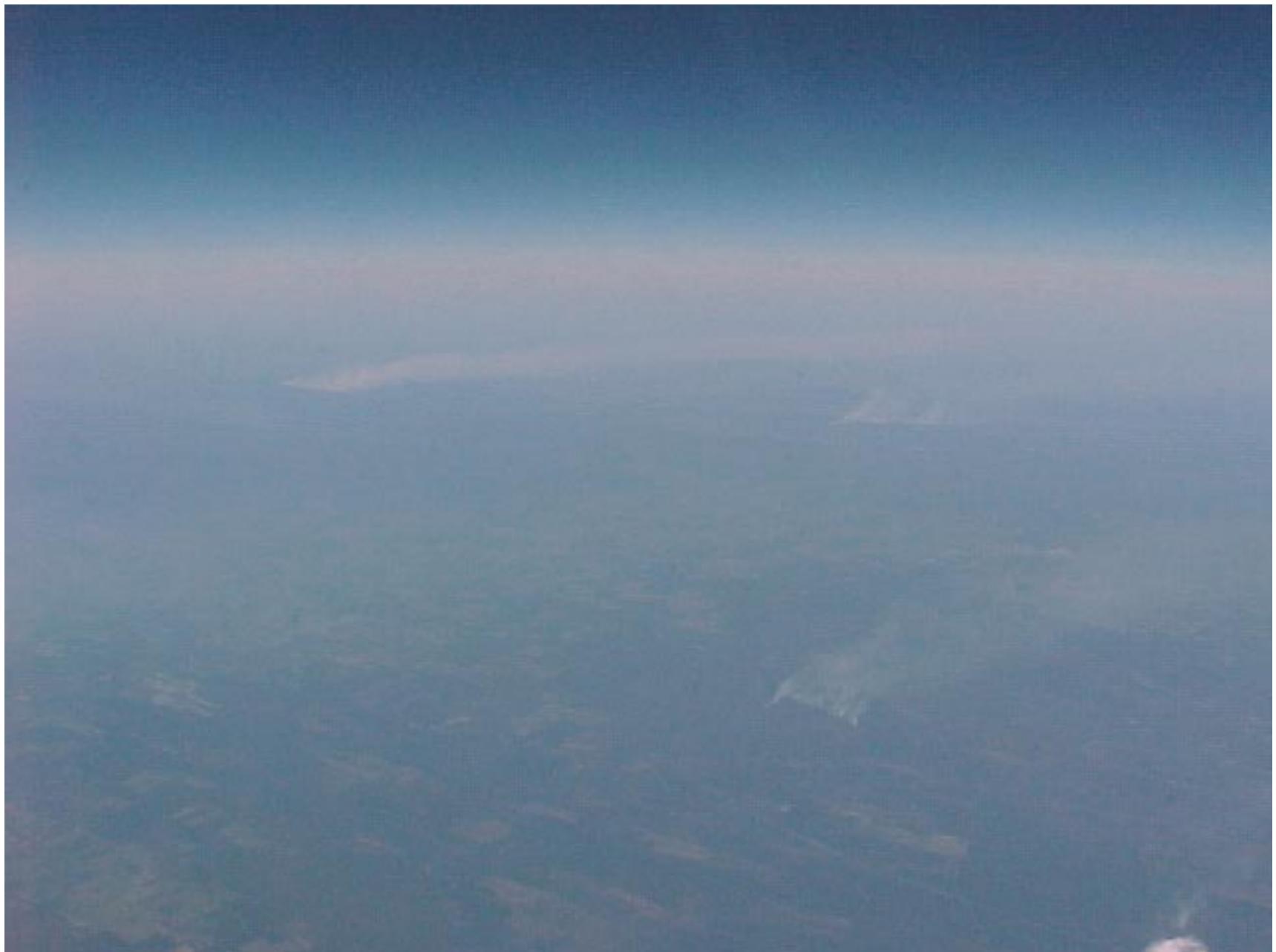
<http://www.ecd.bnl.gov/steve/schwartz.html>

RADIATIVE FORCING OF CLIMATE CHANGE BY AEROSOLS



BIOMASS BURNING AND WIDESPREAD AEROSOL

Northeastern Oklahoma, 2000-12-01

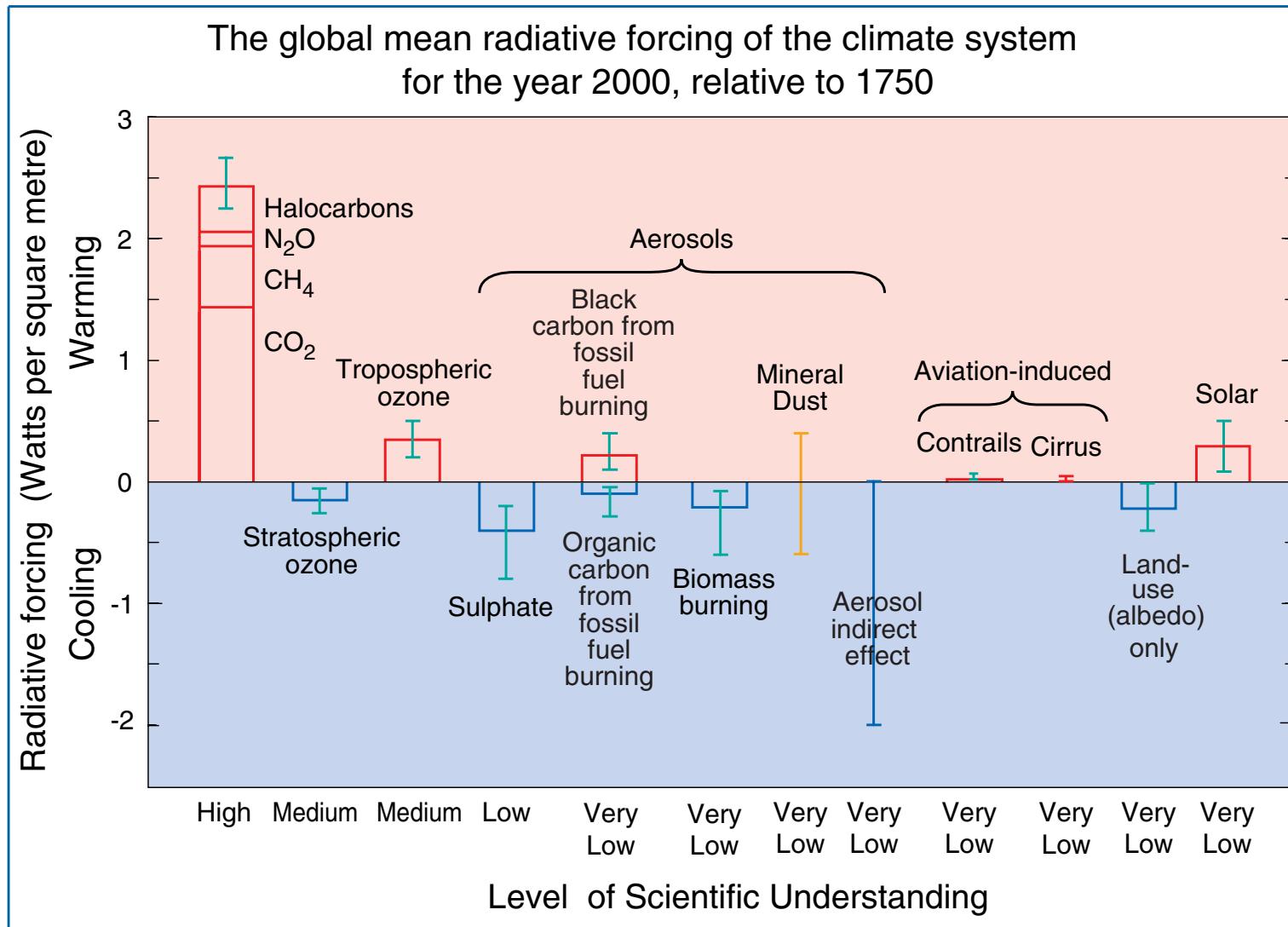


AEROSOL FORCING OF CLIMATE AND CLIMATE CHANGE

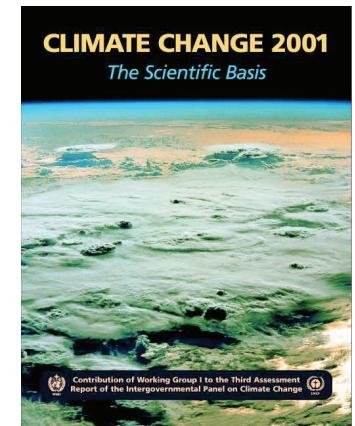
- *Aerosol forcing of climate is difference between radiative flux with aerosol minus radiative flux without aerosol.*
- *Aerosol forcing of climate change is difference between radiative flux with present aerosol minus radiative flux with preindustrial aerosol.*
- *Determination of aerosol forcing of climate change requires attribution of aerosol to anthropogenic vs. natural and determination of aerosol forcing for natural and total aerosol.*

RADIATIVE FORCING OVER THE INDUSTRIAL PERIOD

IPCC (2001)



Summary for Policymakers A Report of Working Group I of the Intergovernmental Panel on Climate Change

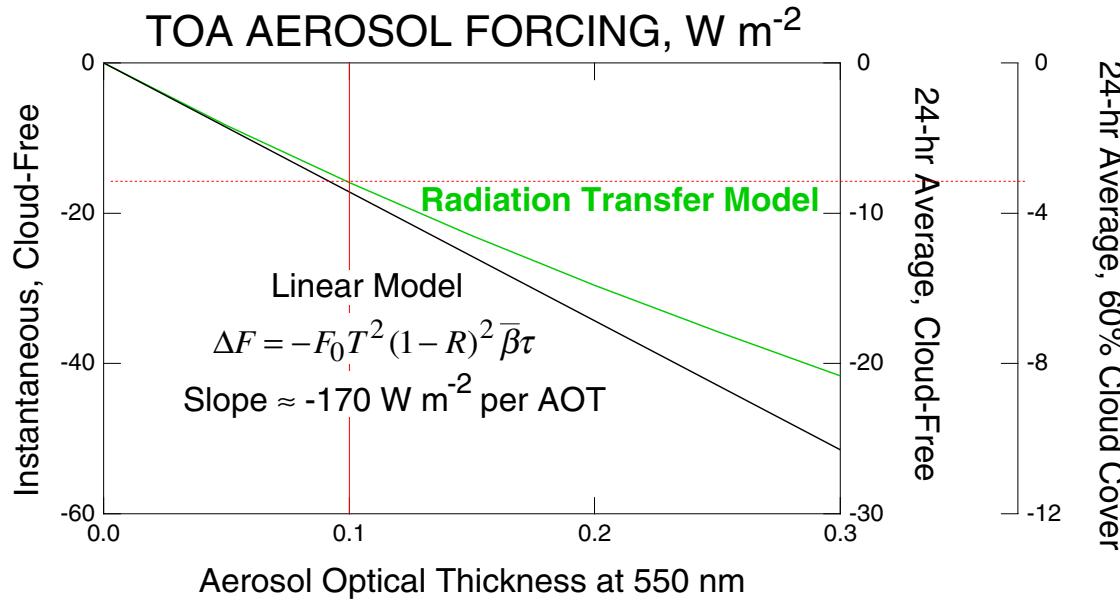


DIRECT EFFECT

DIRECT AEROSOL FORCING

Comparison of linear formula and radiation transfer model

Particle radius $r = 85$ nm; surface reflectance $R = 0.15$; single scatter albedo $\omega_0 = 1$.



Forcing is highly sensitive to modest aerosol loadings.

Global-average AOT 0.1 corresponds to global-average forcing -3.2 W m^{-2} .

Linear model is accurate and convenient, especially for error budgets.

Forcing per optical depth depends on particle size.

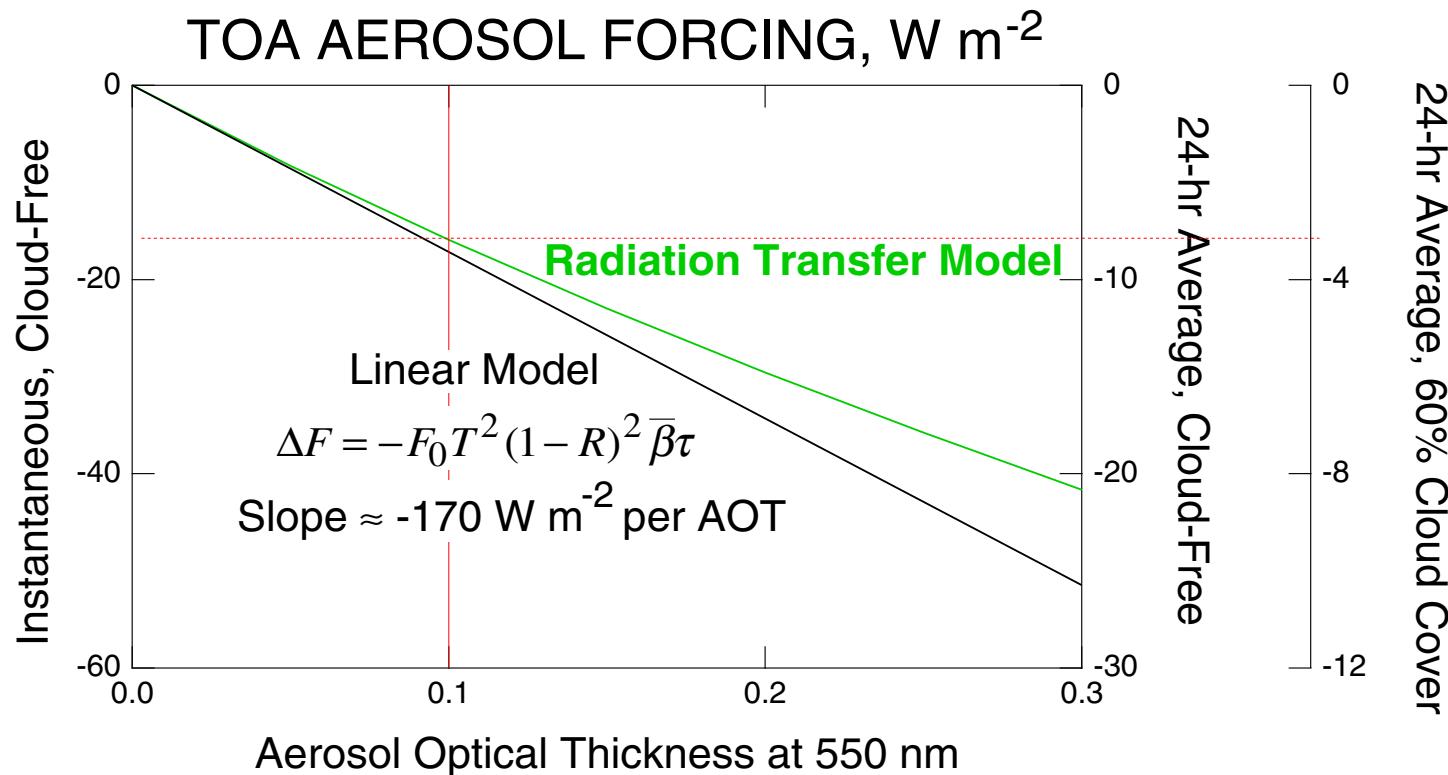
Top-of-atmosphere forcing depends on single scattering albedo and surface reflectance.

DIRECT AEROSOL FORCING AT TOP OF ATMOSPHERE

Dependence on Aerosol Optical Thickness

Comparison of Linear Formula and Radiation Transfer Model

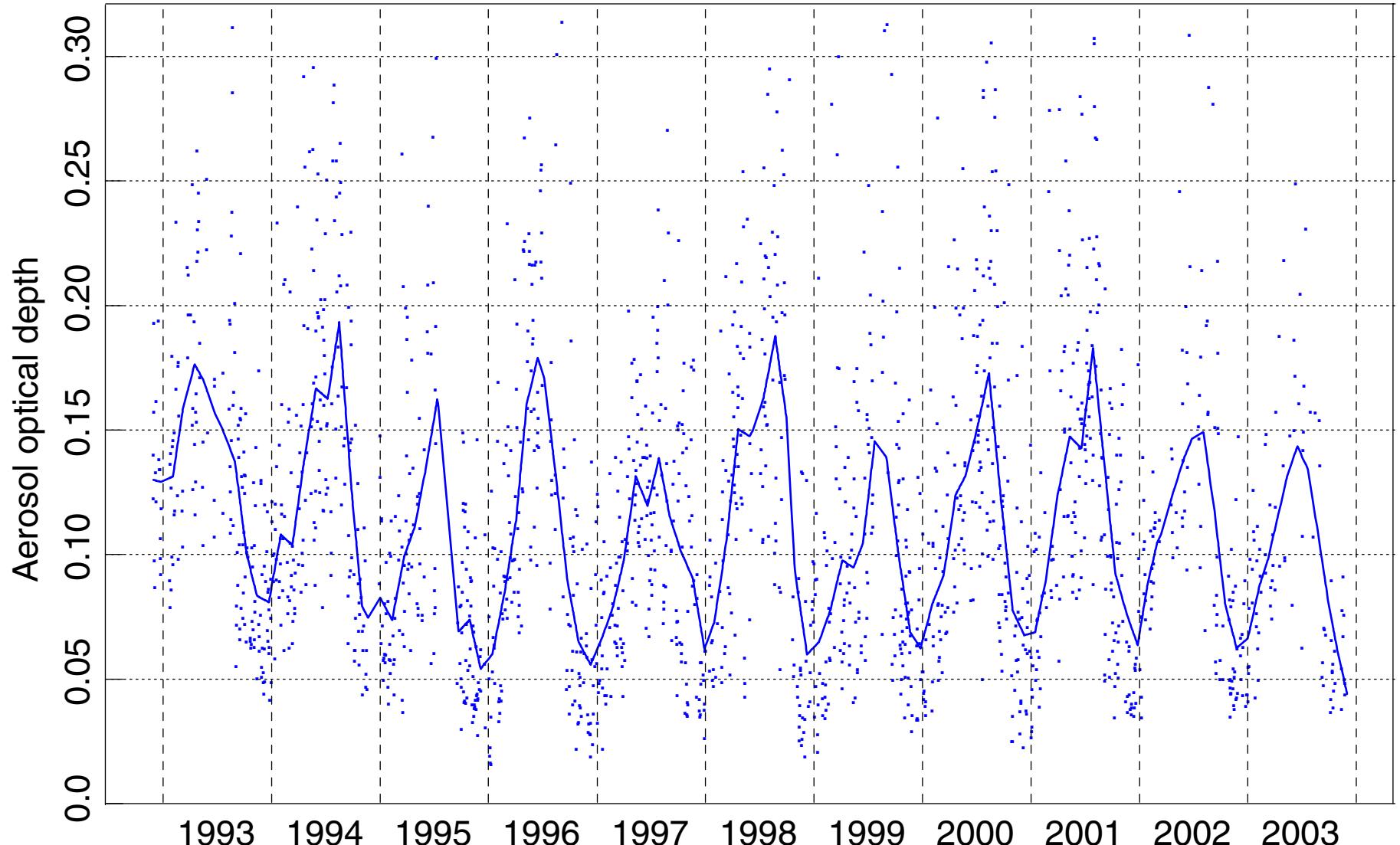
Particle radius $r = 85$ nm; surface reflectance $R = 0.15$; single scatter albedo $\omega_0 = 1$.



Global-average AOT 0.1 corresponds to global-average forcing -3.2 W m^{-2} .

AEROSOL OPTICAL DEPTH

Determined by sunphotometry
North central Oklahoma - Daily average at 500 nm



J. Michalsky et al., JGR, 2001

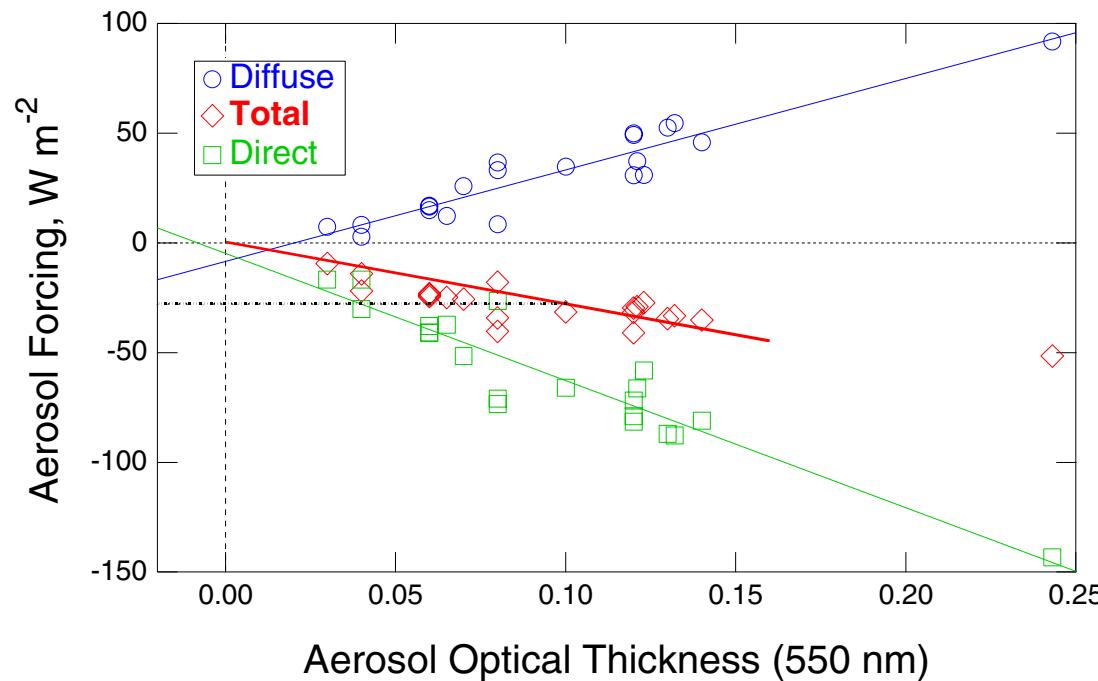
MEASUREMENT OF **DIRECT**, **DIFFUSE**, AND **TOTAL** AEROSOL DIRECT FORCING OF SURFACE IRRADIANCE

- Aerosol direct forcing is difference between surface irradiance with **minus without** aerosol.
- For cloud-free, aerosol-free (Rayleigh) atmosphere, surface irradiance is **calculated** (**direct** and **diffuse** components) for specified illumination geometry, surface reflectance.
- Surface irradiance is **measured** (**direct** and **diffuse** components) in the presence of aerosol of measured optical thickness (sun photometry), for cloud-free sky.
- Direct Aerosol Forcing is **measured** (**direct** and **diffuse** components) as function of aerosol optical thickness as the **difference between measurement and Rayleigh calculation**.

AEROSOL FORCING OF SURFACE IRRADIANCE

Dependence on aerosol optical thickness

Cloud-free sky, DOE ARM Site, North Central Oklahoma



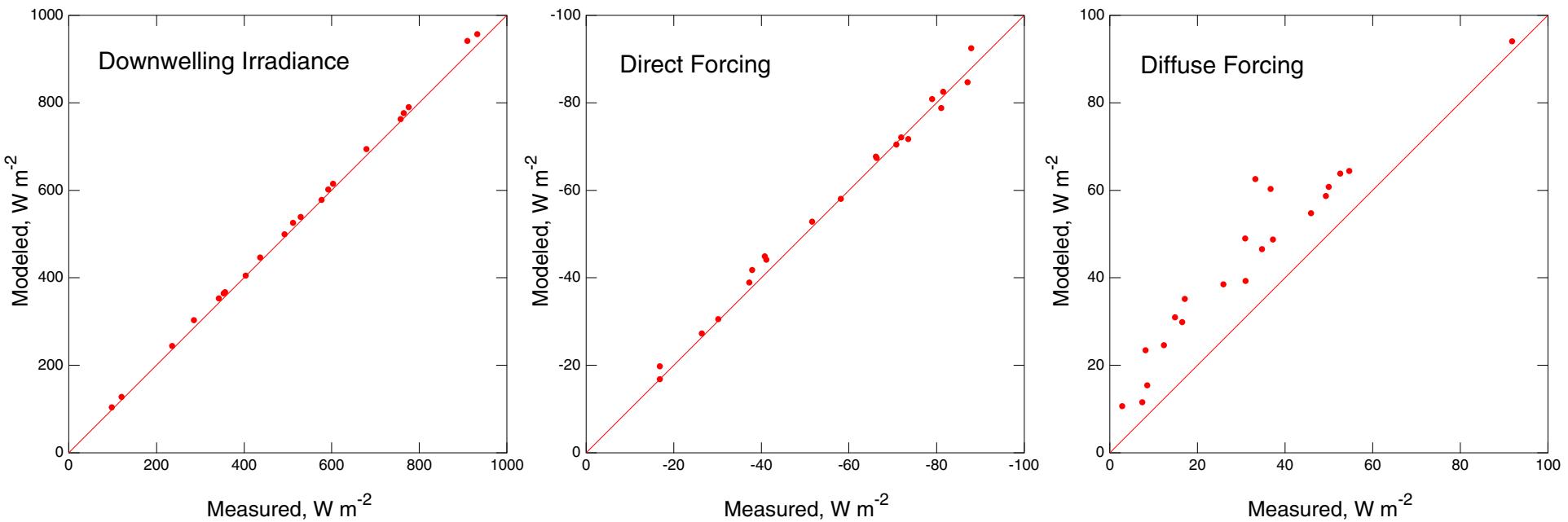
*Aerosol scattering **decreases direct irradiance, increases diffuse irradiance.***

*Aerosols **decrease total surface irradiance** (direct + diffuse) mainly because of upward scattering (top-of-atmosphere forcing) and to lesser extent enhanced atmospheric absorption.*

AEROSOL FORCING OF SURFACE IRRADIANCE

Comparison with Radiation Transfer Model

Cloud-free sky, DOE ARM Site, North Central Oklahoma

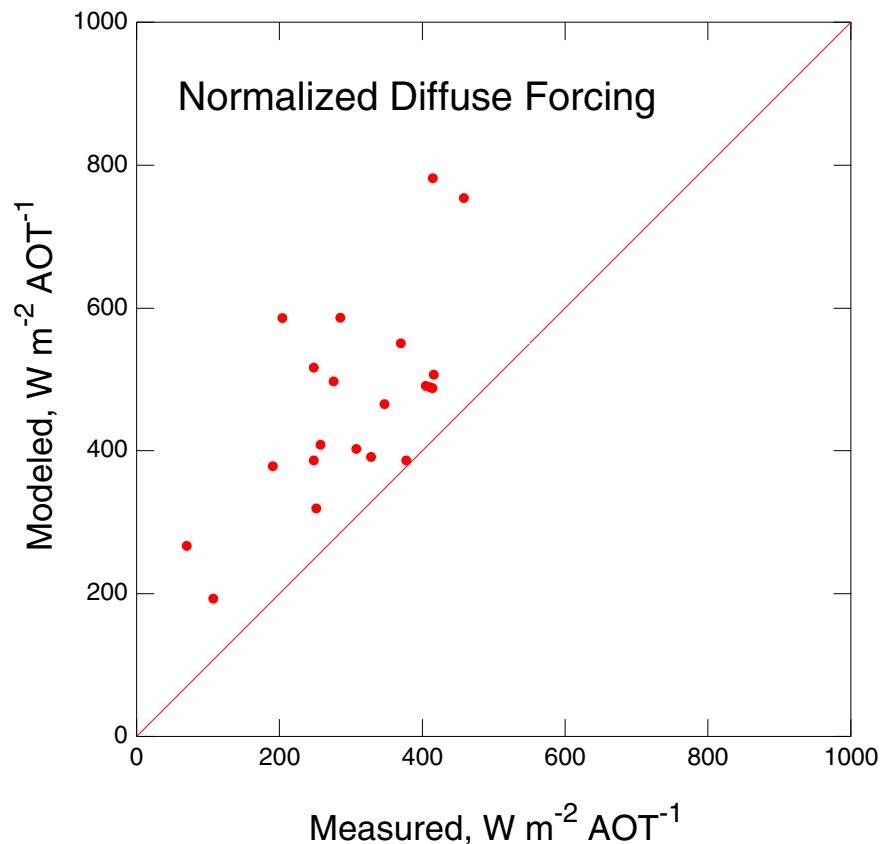
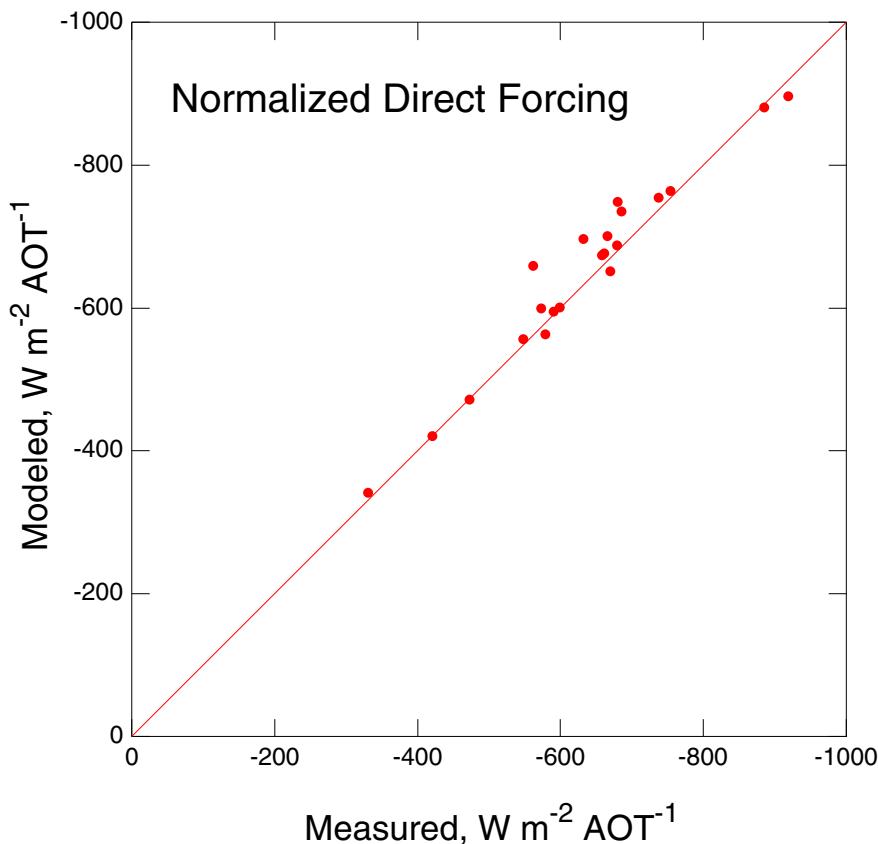


Note systematic discrepancy in diffuse forcing, as revealed also in Halthore *et al.* (*GRL*, 1998) and Halthore and Schwartz (*JGR*, 2000).

AEROSOL FORCING OF SURFACE IRRADIANCE NORMALIZED TO AEROSOL OPTICAL THICKNESS

Comparison with radiation transfer model

Cloud-free sky, DOE ARM Site, North Central Oklahoma



Again note systematic discrepancy in diffuse forcing.

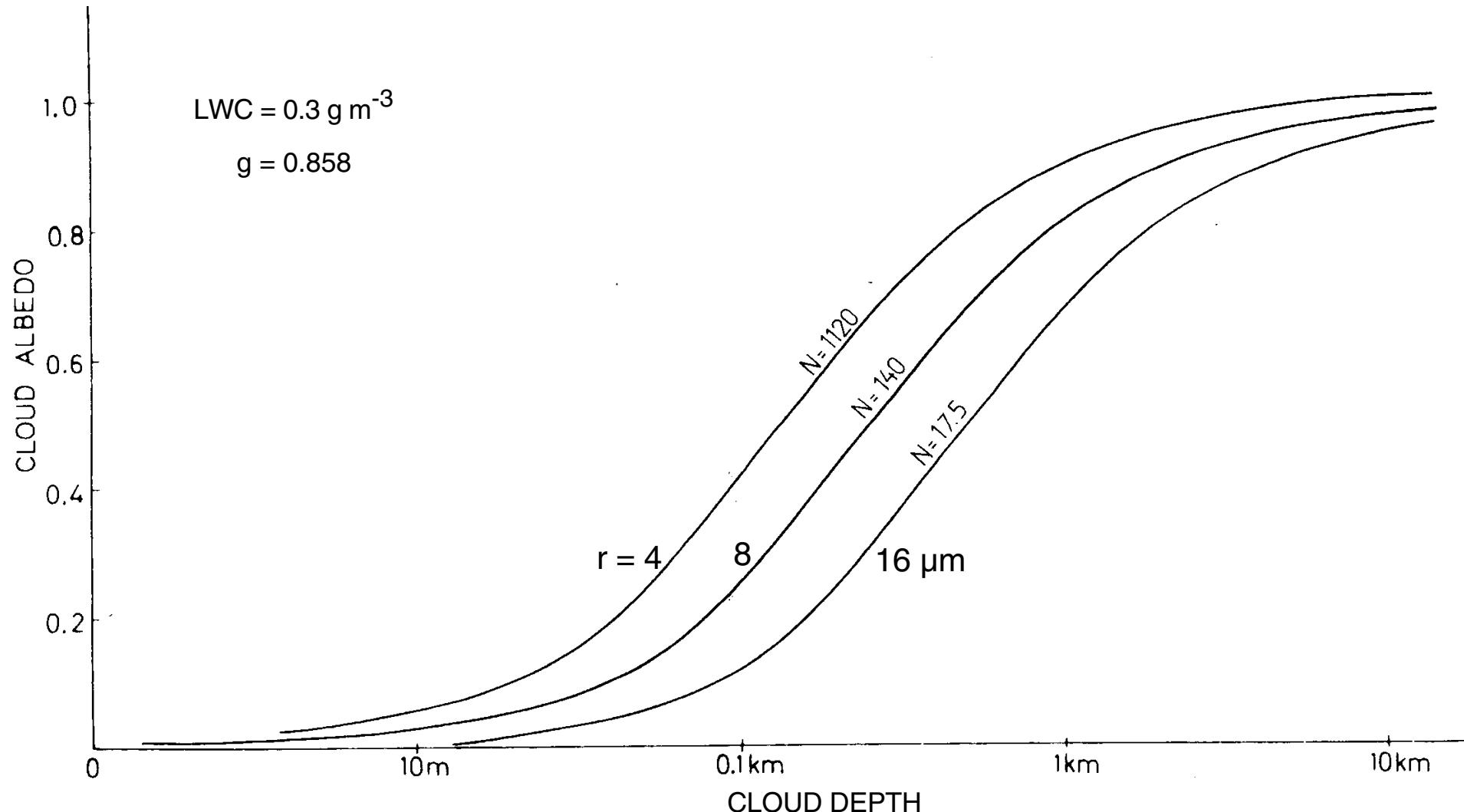
CONCLUSIONS - DIRECT EFFECT STUDY

- *Aerosol surface forcing at SGP is typically a few tens of watts per square meter.*
- *Aerosol surface forcing is not well represented by a constant forcing per optical depth.*
- *Discrepancies remain in calculation of diffuse forcing, necessitating improved characterization of column aerosol optical properties.*
- *A key future goal is determination of aerosol TOA forcing by ground-based remote sensing.*

INDIRECT EFFECT

DEPENDENCE OF CLOUD ALBEDO ON CLOUD DEPTH

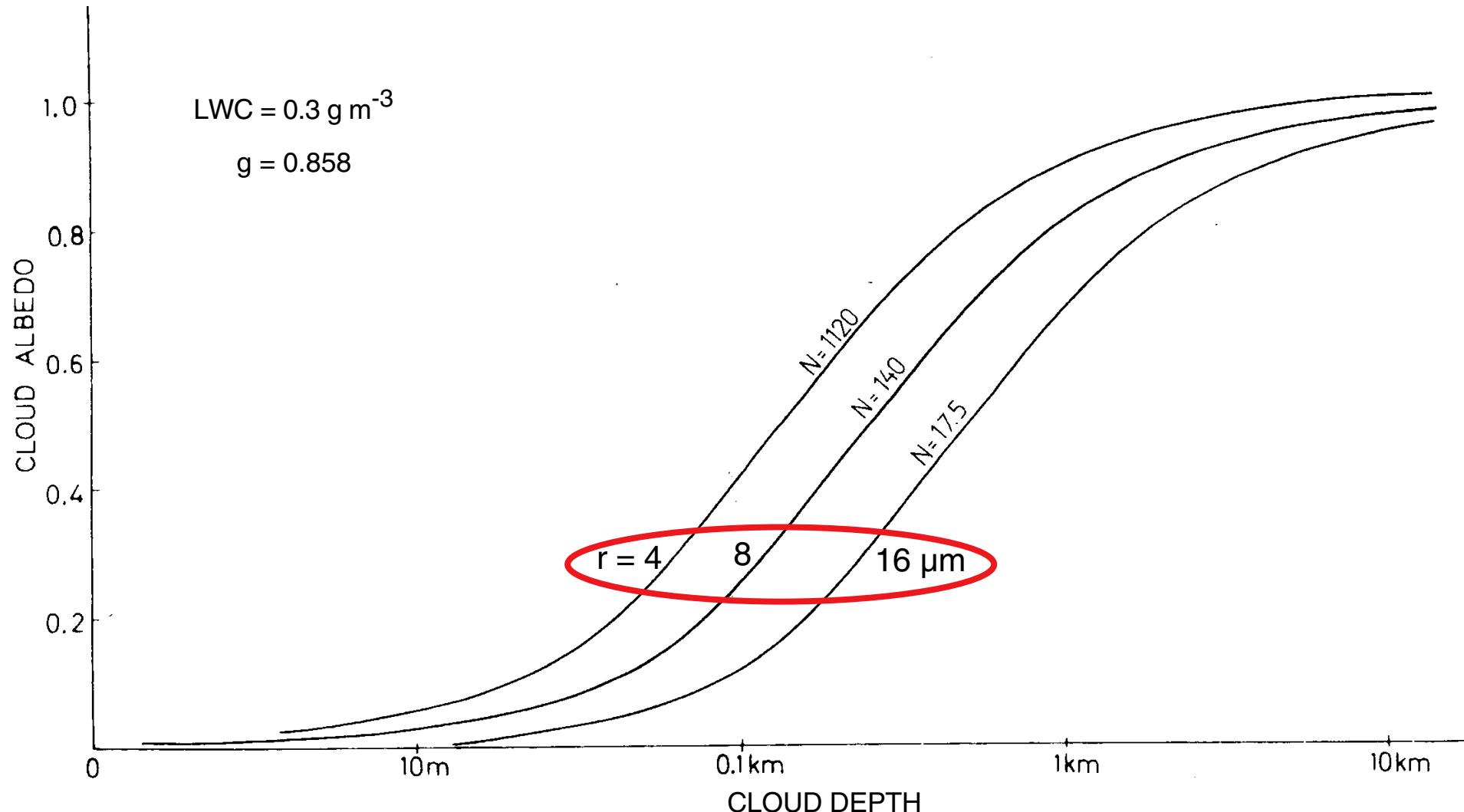
Influence of Cloud Drop Radius and Concentration



Twomey, *Atmospheric Aerosols*, 1977

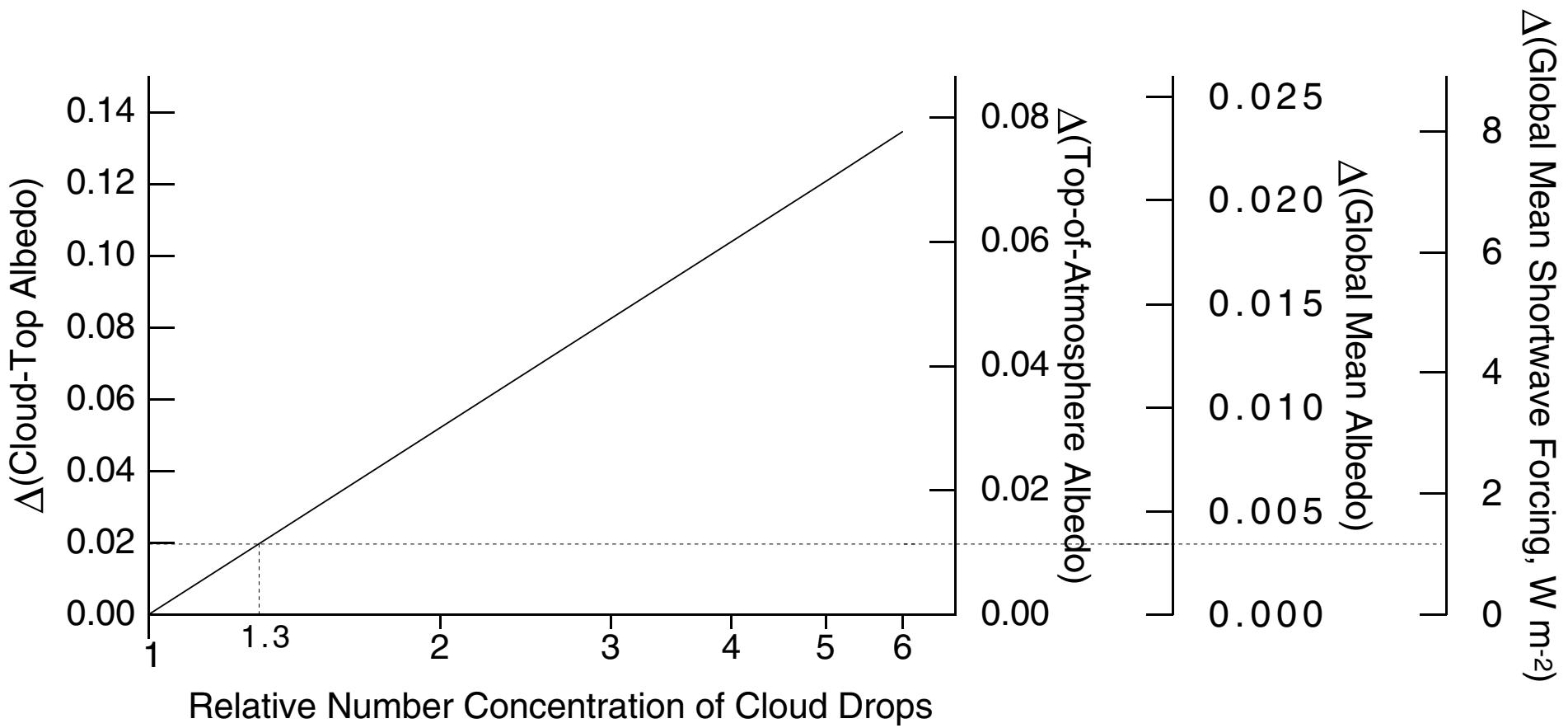
DEPENDENCE OF CLOUD ALBEDO ON CLOUD DEPTH

Influence of Cloud Drop Radius and Concentration



Twomey, *Atmospheric Aerosols*, 1977

SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION

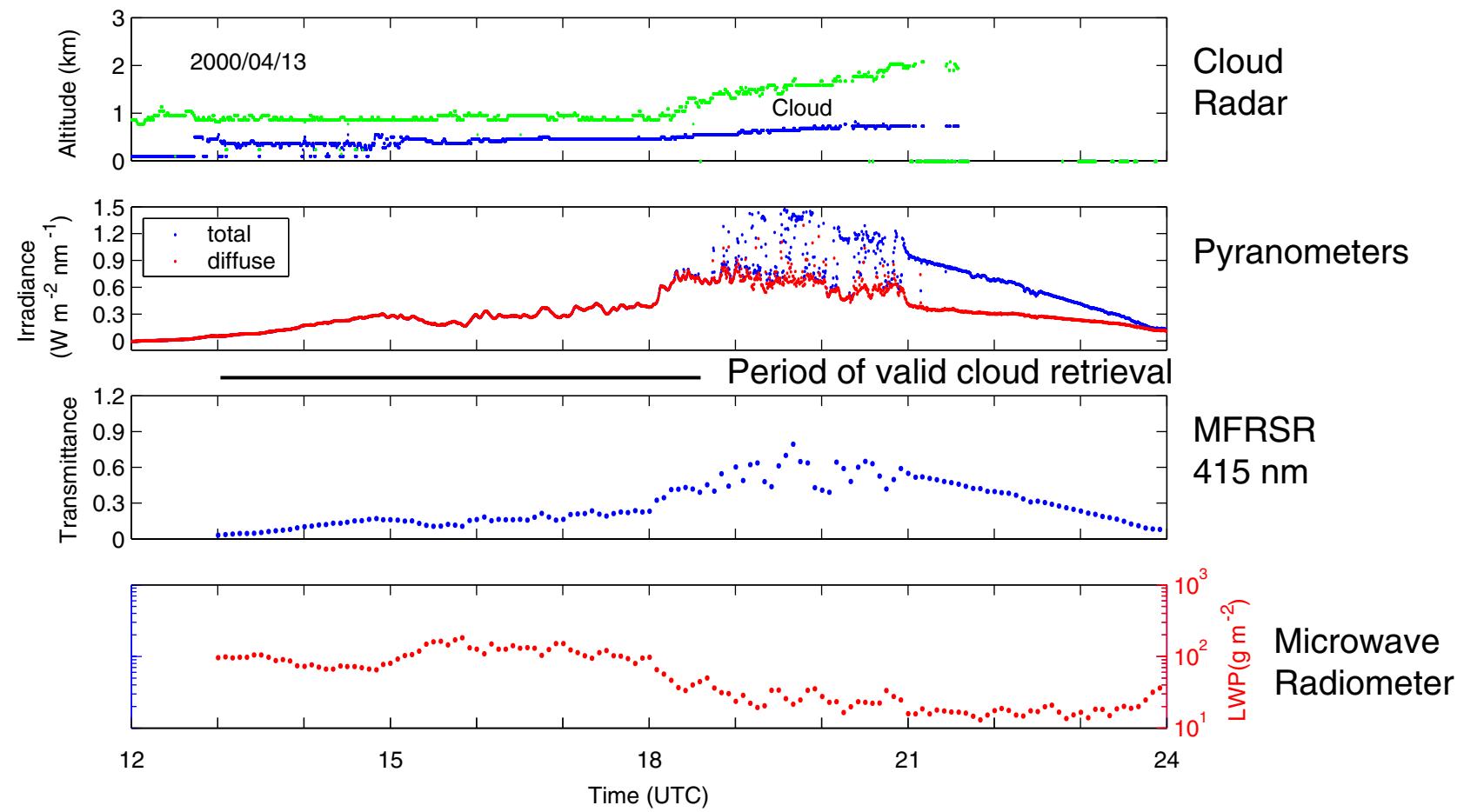


Schwartz and Slingo (1996)

For constant cloud liquid water, a decrease in cloud drop radius by 10% increases cloud droplet number concentration by 30%, and a halving of cloud drop radius increases cloud droplet concentration by a factor of 8.

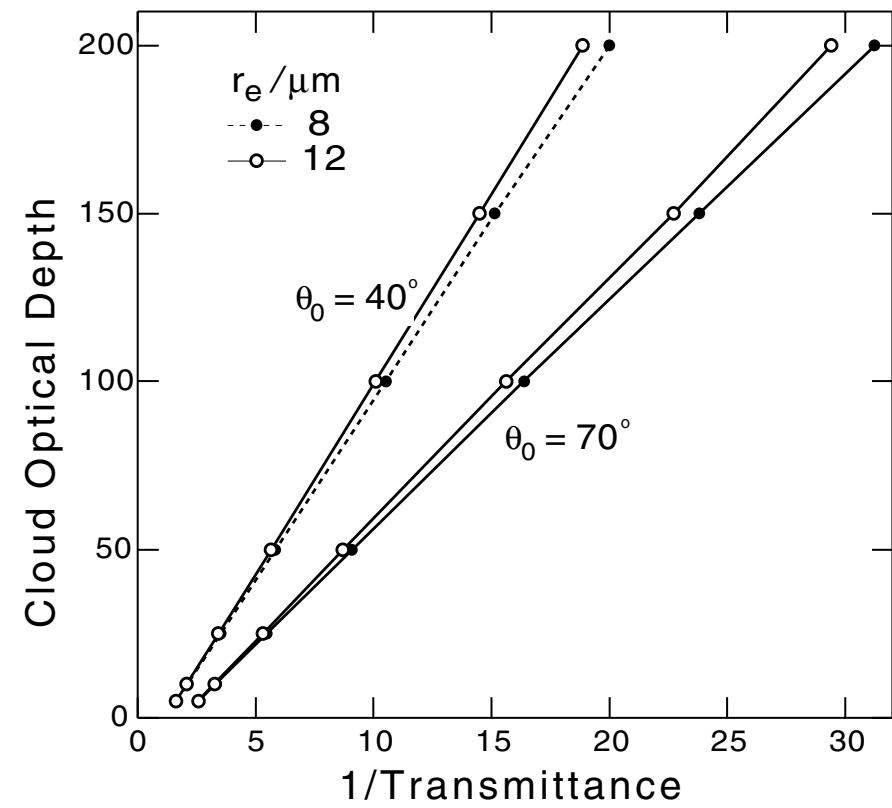
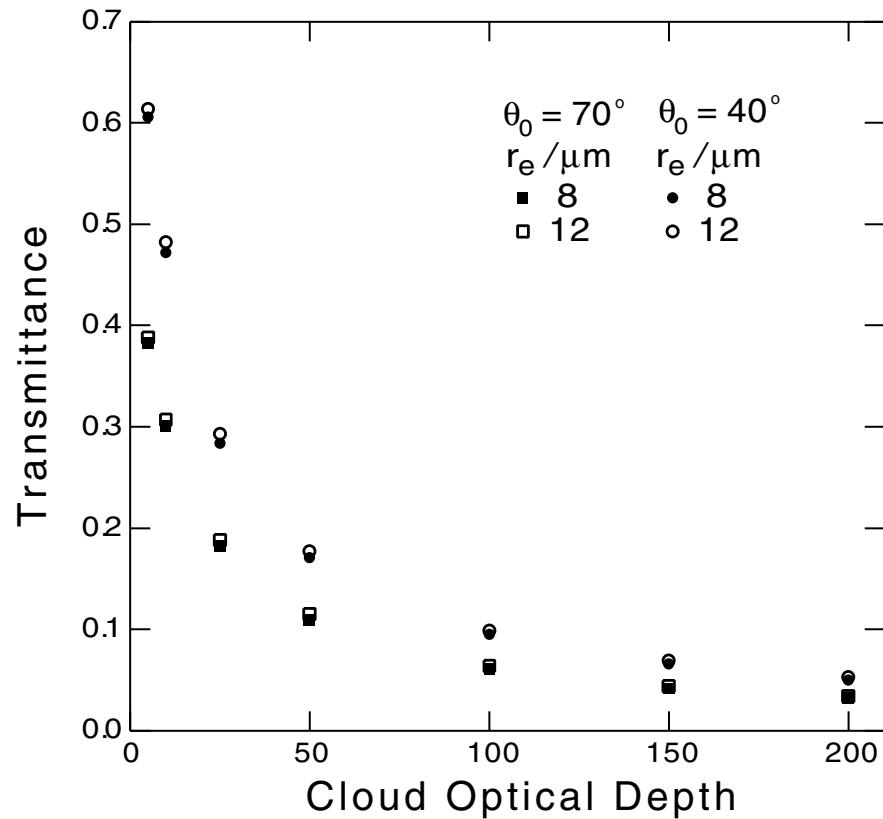
GROUND BASED REMOTE SENSING OF CLOUD PROPERTIES

North Central Oklahoma, April 13, 2000 Local time = UTC - 6h



Kim, Schwartz, Miller, and Min, JGR, 2003

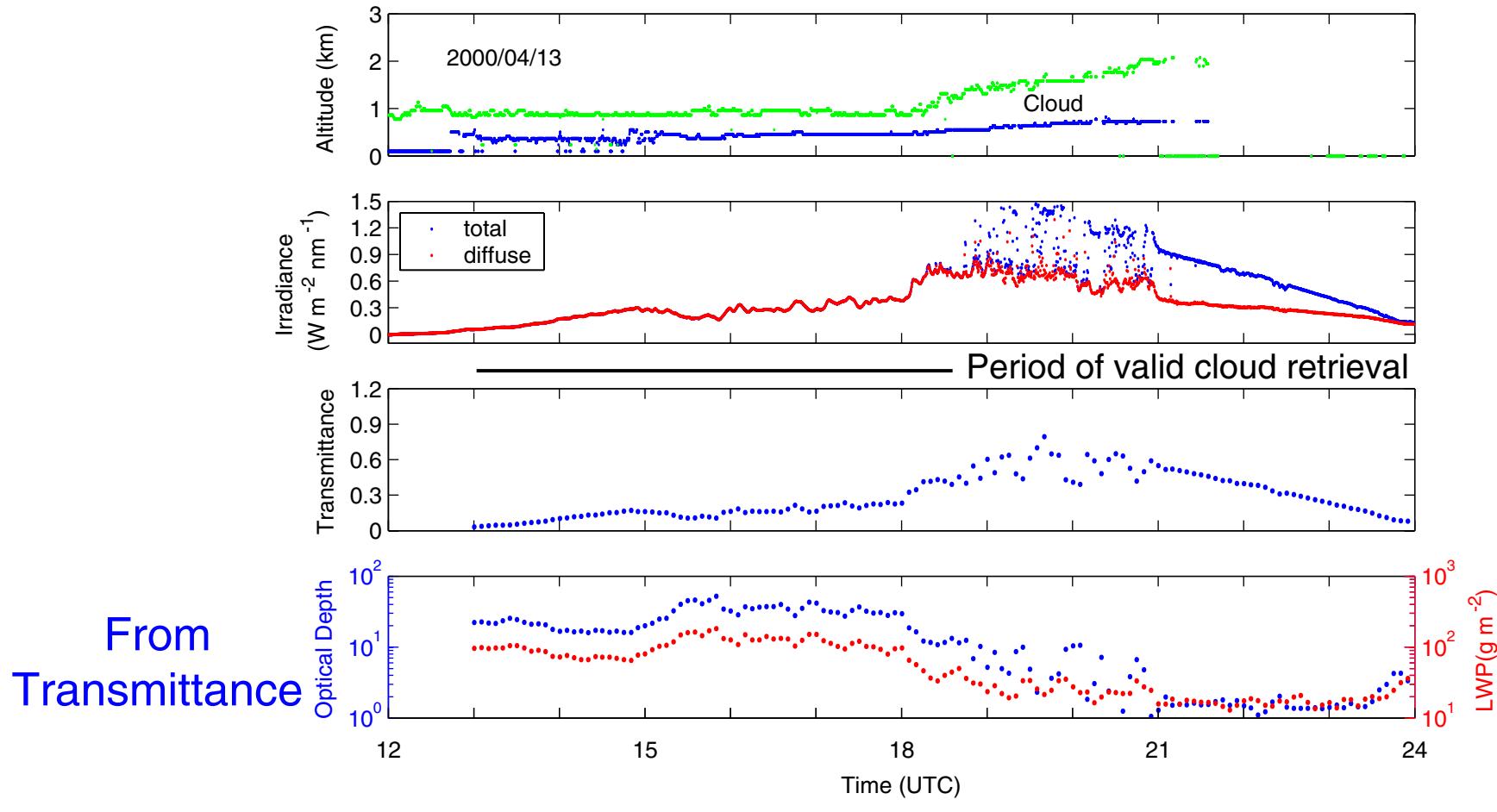
RELATION BETWEEN ATMOSPHERIC TRANSMITTANCE AND CLOUD OPTICAL DEPTH



Kim, Schwartz, Miller, and Min, JGR, 2003

GROUND BASED REMOTE SENSING OF CLOUD PROPERTIES

North Central Oklahoma, April 13, 2000 – Local time = UTC - 6



Kim, Schwartz, Miller, and Min, JGR, 2003

MEASURING CLOUD DROP EFFECTIVE RADIUS BY GROUND BASED REMOTE SENSING

Effective radius: Cloud or aerosol property important for radiative transfer

For a homogeneous volume

$$r_e \equiv \frac{\mu_3}{\mu_2} \equiv \frac{\int N(r) r^3 dr}{\int N(r) r^2 dr}$$

For a cloud

$$r_e = \frac{\iint N(r, z) r^3 dr dz}{\iint N(r, z) r^2 dr dz}$$

*Cloud liquid water path (LWP)
(microwave radiometer)*

$$L = \frac{4\pi}{3} \rho_w \iint r^3 N(r, z) dr dz$$

*Cloud optical depth
(MFRSR)*

$$\tau_c = \iint \pi r^2 Q_e(r) N(r, z) dr dz$$

Mie scattering efficiency

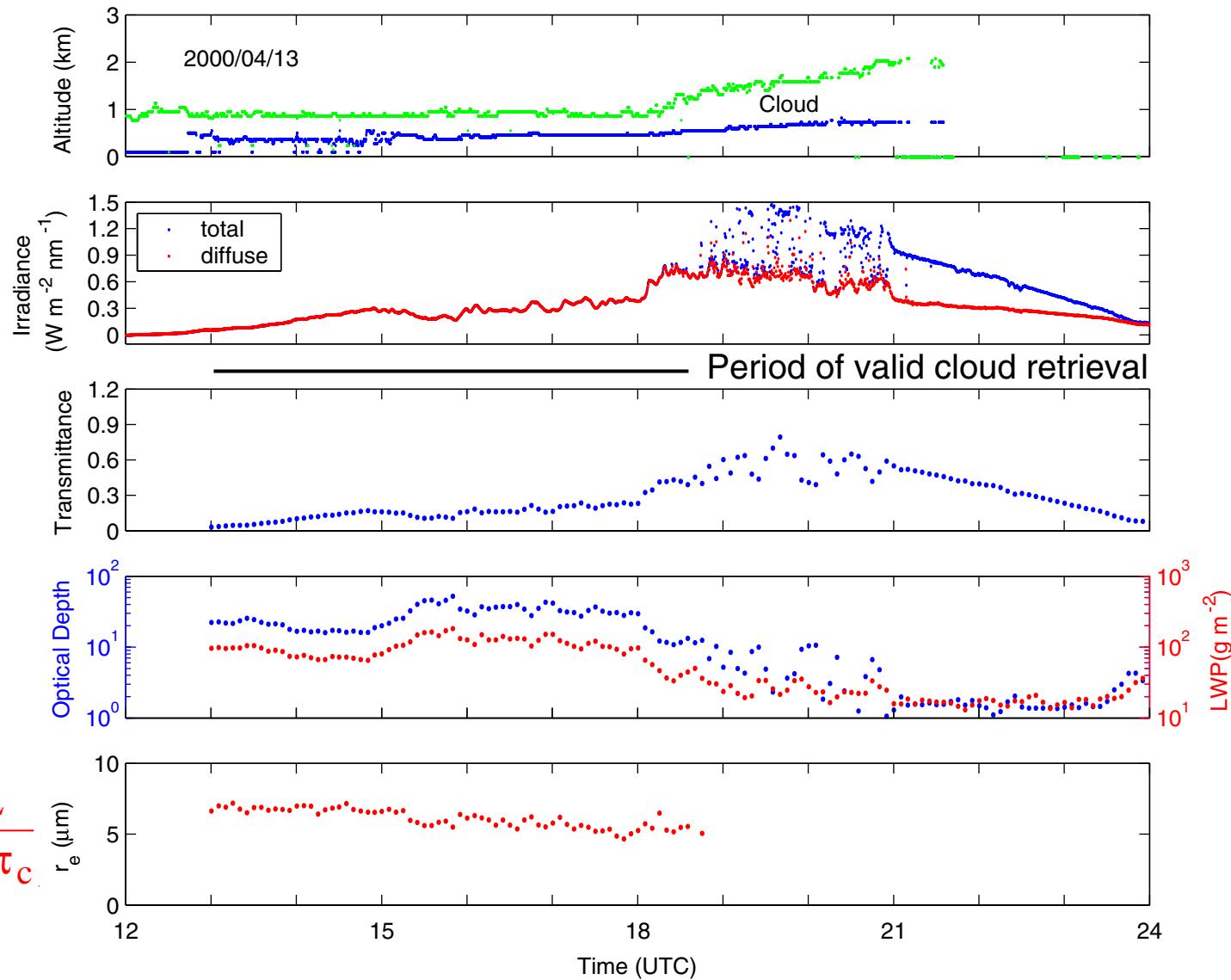
$$Q_e \approx 2 \text{ for } r \gg \lambda$$

Whence

$$r_e \approx \frac{3}{2} \frac{L}{\rho_w \tau_c}$$

GROUND BASED REMOTE SENSING OF CLOUD PROPERTIES

North Central Oklahoma, April 13, 2000 – Local time = UTC - 6

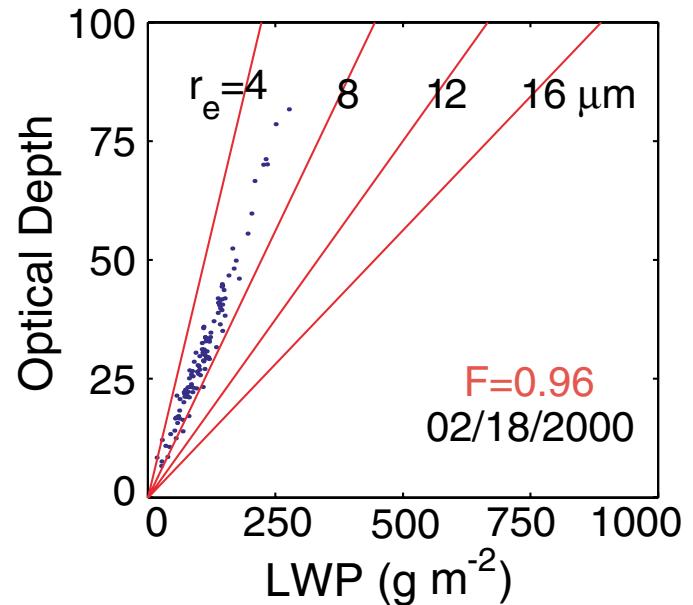


Kim, Schwartz, Miller, and Min, JGR, 2003

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

North Central Oklahoma, 2000

$$\tau_c \approx \frac{3}{2} \frac{L}{\rho_w r_e}$$



Kim, Schwartz, Miller, and Min, JGR, 2003

Optical depth is highly correlated with and strongly dependent on liquid water path.

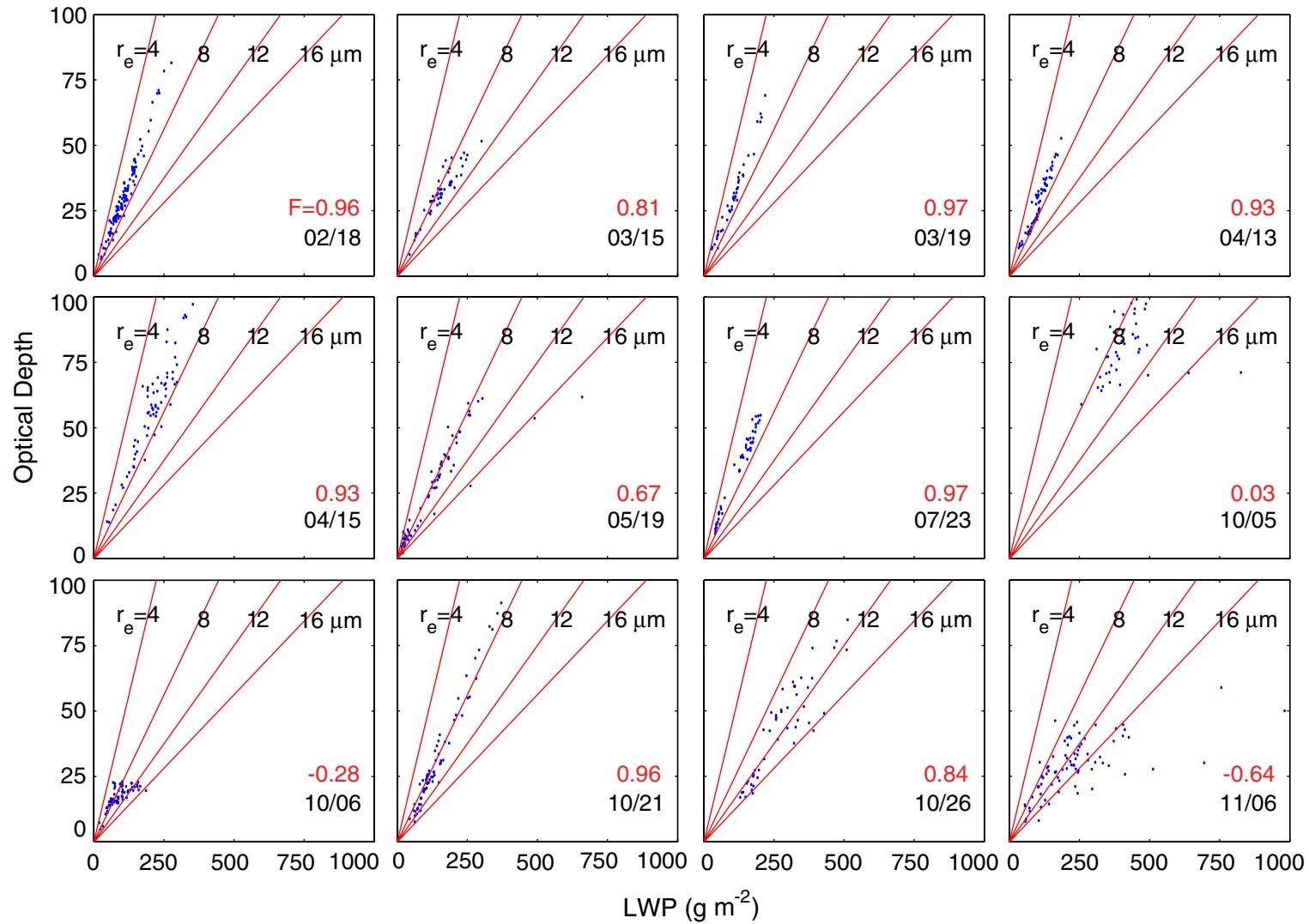
Tight cluster of points about a diagonal line through the origin is indicative of constant effective radius over the day.

Slope is inversely proportional to effective radius.

F, fraction of variance accounted for by regression = 96%.

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

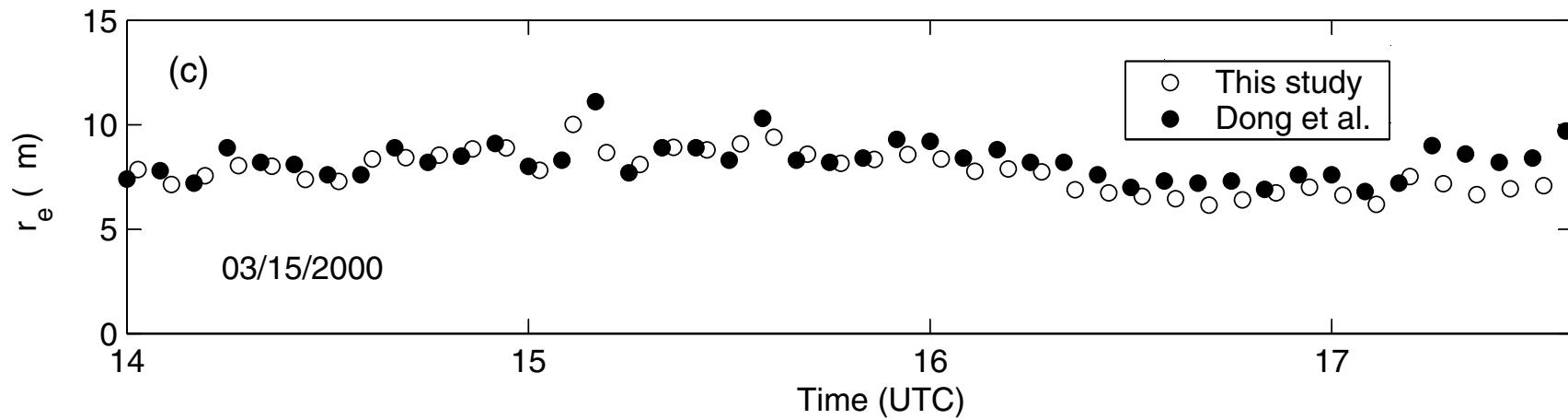
North Central Oklahoma, 2000



Kim, Schwartz, Miller, and Min, JGR, 2003

F, fraction of variance accounted for by regression, mainly > 80%.

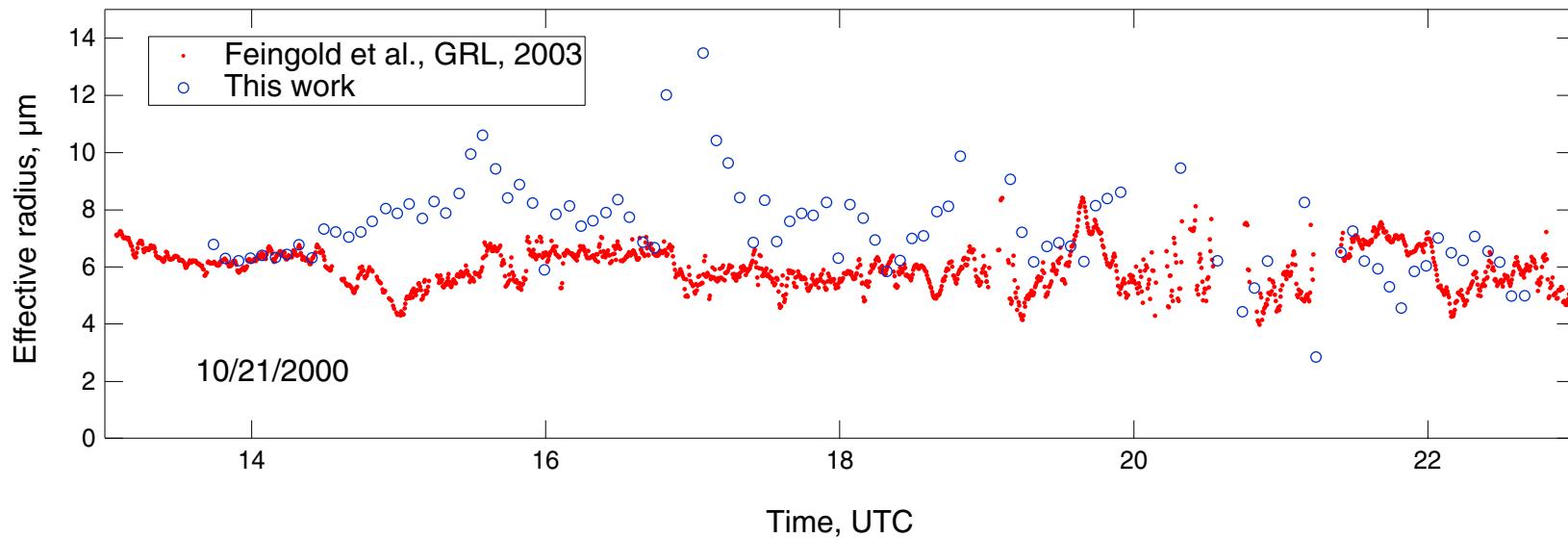
COMPARISON WITH OTHER MEASUREMENTS



Kim, Schwartz, Miller, and Min, JGR, 2003

Dong et al. use broadband visible optical depth and slightly different algorithm for LWP from microwave radiometer.

COMPARISON WITH OTHER MEASUREMENTS

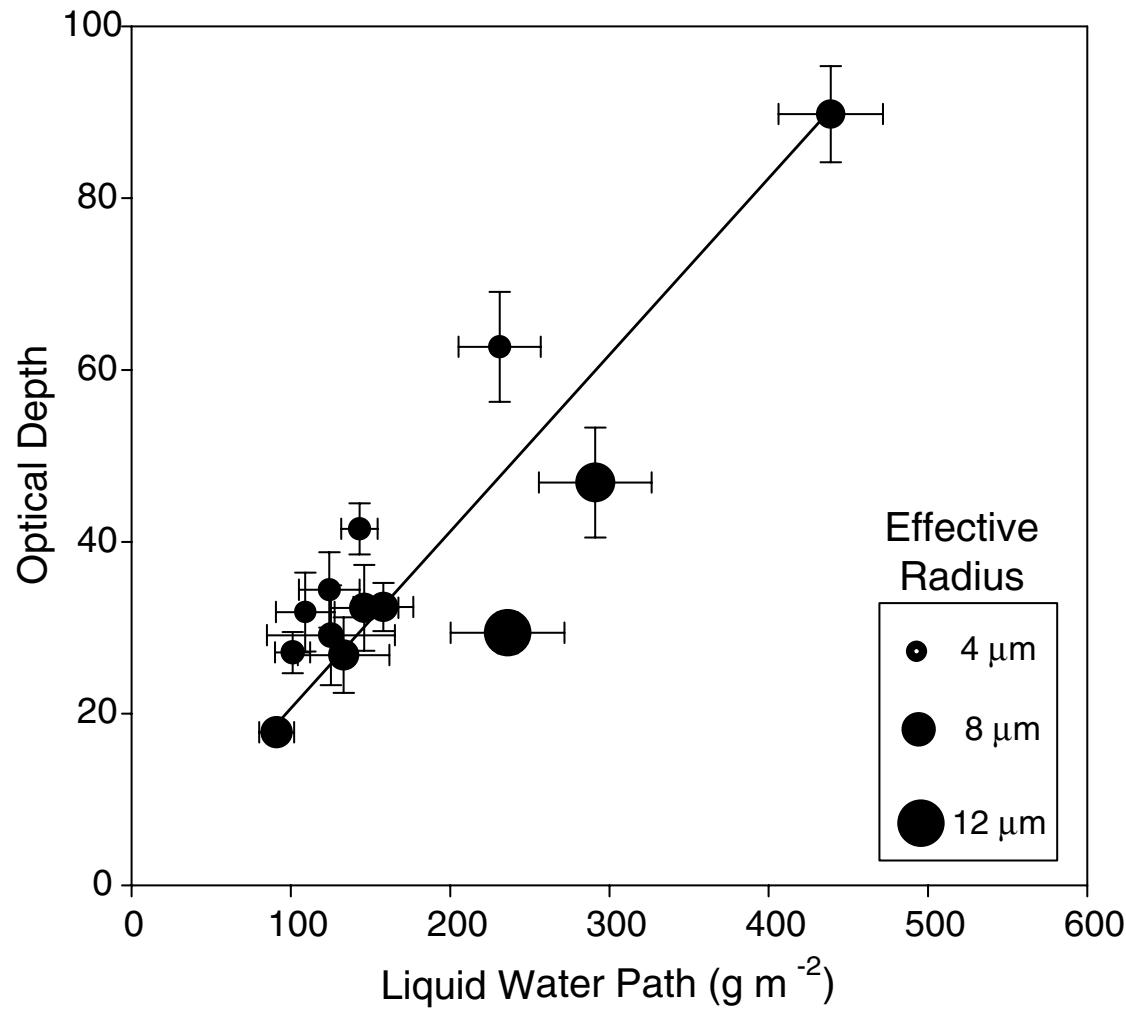


Feingold et al. obtain effective radius from cloud radar.

Reasons for discrepancies are not known and need investigation.

CLOUD OPTICAL DEPTH VS. LIQUID WATER PATH

North Central Oklahoma, 2000, aggregated by days



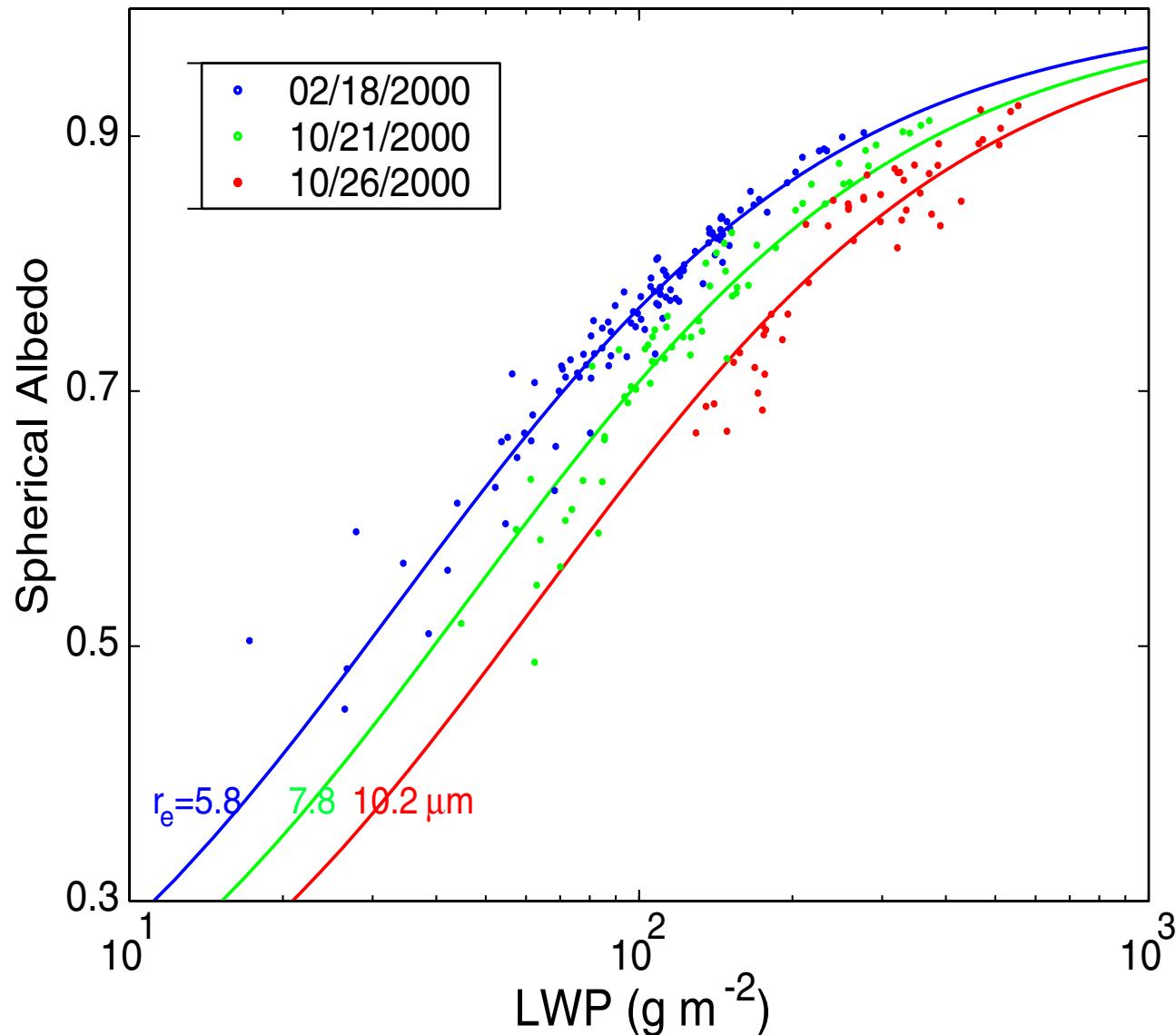
Kim, Schwartz, Miller, and Min, JGR, 2003

Fraction of variance accounted for by regression, 74%.

Days with smaller radii have a greater optical depth for a given LWP

CLOUD ALBEDO CALCULATED FROM MEASURED EFFECTIVE RADIUS AND LIQUID WATER PATH

North Central Oklahoma



Kim, Schwartz, Miller, and Min, JGR, 2003

RADIATIVE FORCING DUE TO DIFFERENCES IN EFFECTIVE RADIUS

Radiative forcing calculation for solar zenith angle 60°
and liquid water path 100 g m⁻²

Date, 2000	Effective radius r_e , μm	Optical Depth	Net flux at TOA W m ⁻²	Forcing relative to 10/26, W m ⁻²
10/26	10.2	15.1	293	—
10/21	7.8	20.8	266	27
02/18	5.8	28.3	240	53

Kim, Schwartz, Miller, and Min, JGR, 2003

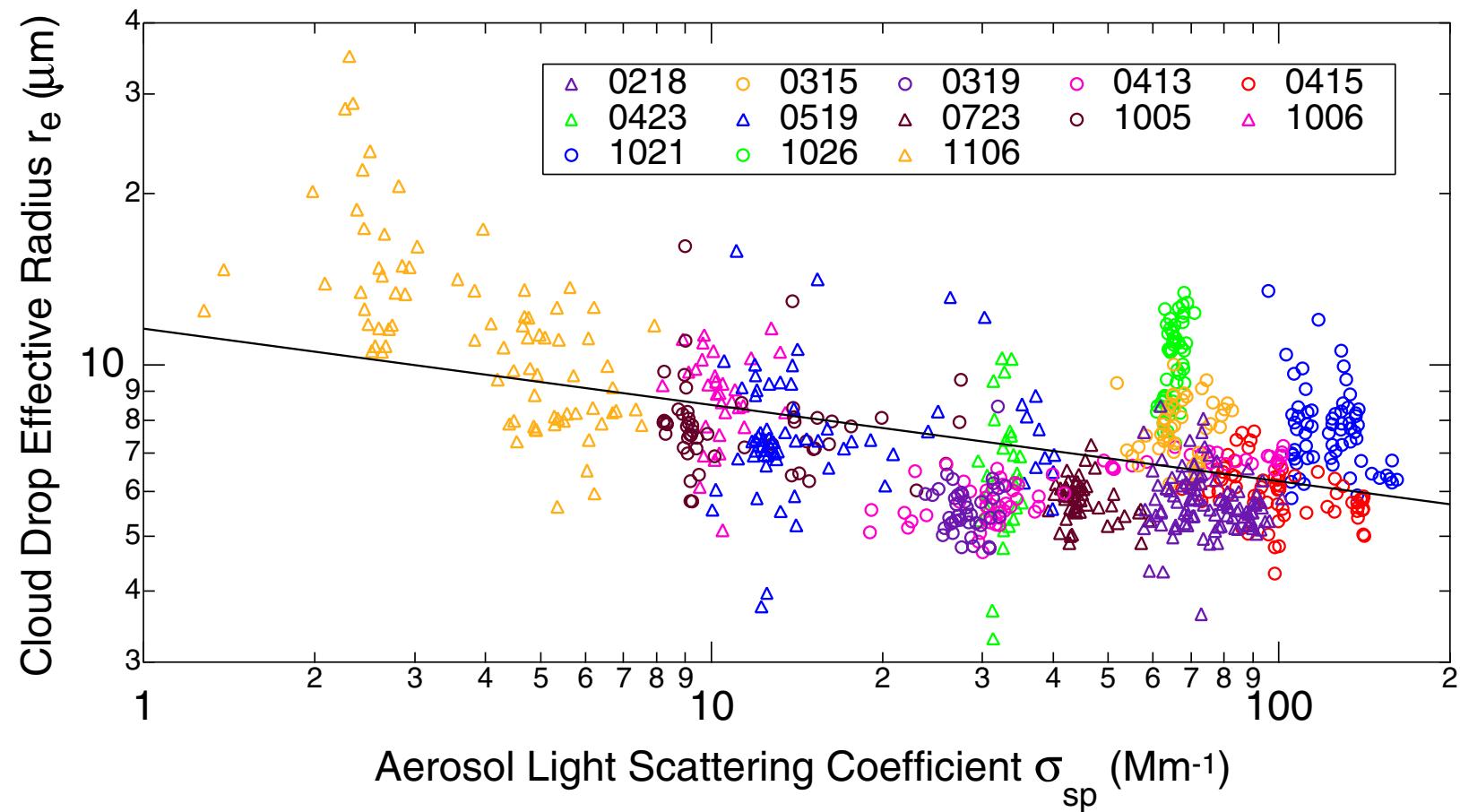
To what extent can this be attributed to aerosols?

CORRELATION OF CLOUD DROP EFFECTIVE RADIUS AND AEROSOL LIGHT SCATTERING COEFFICIENT

North Central Oklahoma

All days in 2000 meeting complete overcast criterion

$$R^2 = 0.24$$



Kim, Schwartz, Miller, and Min, JGR, 2003

CONCLUSIONS - INDIRECT EFFECT STUDY

Ground-based remote sensing of cloud-drop effective radius is yields column average quantity, pertinent to radiative transfer.

The dominant influence on cloud optical depth τ_c is Liquid Water Path (LWP). LWP accounts for 63% of the variance in τ_c over the entire data set and up to 97% of the variance on a given day.

Effective radius r_e varies little on a given day. Daily average varied substantially, from 5.6 ± 0.1 to $12.3 \pm 0.6 \mu\text{m}$.

Effective radius exerts an important influence on calculated cloud albedo and TOA net flux, up to $\sim 50 \text{ W m}^{-2}$ for otherwise constant conditions.

Effective radius is weakly correlated with aerosol light scattering at the surface.

